AD NUMBER

AD055062

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; FEB 1955. Other requests shall be referred to Army Medical Research Laboratory, Fort Knox, KY.

AUTHORITY

USAMRL ltr, 26 Feb 1970

ARMY MEDICAL RESEARCH LABORATORY

FORT KNOX, KENTUCKY

REPORT NO. 176
8 February 1955

PERFORMANCE WITH LIGHT-WEIGHT GRENADES AS A FUNCTION OF WEIGHT AND DISTANCE*

*Subtask under PSYCHOPHYSIOLOGICAL STUDIES, AMRL Project No. 6-95-20-001, Subtask, Control Coordination Studies.

RESEARCH AND DEVELOPMENT DIVISION
OFFICE OF THE SURGEON GENERAL
DEPARTMENT OF THE ARMY

Best
Available
Copy

Enclosure to AD 55062

Report No. 176

From Project No. 6-95-20-001

PERFORMANCE WITH LIGHT-WEIGHT GRENADES AS A FUNCTION OF WEIGHT AND DISTANCE

by

D. O. Hartman and R. E. Page

from

Psychology Department

Submitted

30 December 1954

20 pp & ii   10 illus.

Abstract;

Grenades weighing 2, 4, 6, 8 and 10 ounces were thrown at targets located 10, 15, 20, 25, 30 and 35 yards from the subject. Each increase in distance resulted in a decrement in the accuracy and consistency of throwing. Weight significantly altered both accuracy and consistency. With the exception of the 2-ounce grenade, there was a trend for decreasing accuracy with increasing weight.

Army Medical Research Lab   Project No. 6-95-20-001   Report No. 176

PERFORMANCE WITH LIGHT-WEIGHT GRENADES AS A FUNCTION OF WEIGHT AND DISTANCE

B. O. Hartman and R. E. Page

20 pp & ii   10 illus.   30 December 1954

UNCLASSIFIED

Grenades weighing 2, 4, 6, 8, and 10 ounces were thrown at targets located 10, 15, 20, 25, 30, and 35 yards from the subject. Each increase in distance resulted in a decrement in the accuracy and consistency of throwing. Weight significantly altered both accuracy and consistency. With the exception of the 2-ounce grenade, there was a trend for decreasing accuracy with increasing weight.

1. Psychology   2. Motor Skills   3. Control Coordination

Army Medical Research Lab   Project No. 6-95-20-001   Report No. 176

PERFORMANCE WITH LIGHT-WEIGHT GRENADES AS A FUNCTION OF WEIGHT AND DISTANCE

B. O. Hartman and R. E. Page

20 pp & ii   10 illus.   30 December 1954

UNCLASSIFIED

Grenades weighing 2, 4, 6, 8, and 10 ounces were thrown at targets located 10, 15, 20, 25, 30, and 35 yards from the subject. Each increase in distance resulted in a decrement in the accuracy and consistency of throwing. Weight significantly altered both accuracy and consistency. With the exception of the 2-ounce grenade, there was a trend for decreasing accuracy with increasing weight.

1. Psychology   2. Motor Skills   3. Control Coordination

Army Medical Research Lab   Project No. 6-95-20-001   Report No. 176

PERFORMANCE WITH LIGHT-WEIGHT GRENADES AS A FUNCTION OF WEIGHT AND DISTANCE

B. O. Hartman and R. E. Page

20 pp & ii   10 illus.   30 December 1954

UNCLASSIFIED

Grenades weighing 2, 4, 6, 8, and 10 ounces were thrown at targets located 10, 15, 20, 25, 30, and 35 yards from the subject. Each increase in distance resulted in a decrement in the accuracy and consistency of throwing. Weight significantly altered both accuracy and consistency. With the exception of the 2-ounce grenade, there was a trend for decreasing accuracy with increasing weight.

1. Psychology   2. Motor Skills   3. Control Coordination

Army Medical Research Lab   Project No. 6-95-20-001   Report No. 176

PERFORMANCE WITH LIGHT-WEIGHT GRENADES AS A FUNCTION OF WEIGHT AND DISTANCE

B. O. Hartman and R. E. Page

20 pp & ii   10 illus.   30 December 1954

UNCLASSIFIED

Grenades weighing 2, 4, 6, 8, and 10 ounces were thrown at targets located 10, 15, 20, 25, 30, and 35 yards from the subject. Each increase in distance resulted in a decrement in the accuracy and consistency of throwing. Weight significantly altered both accuracy and consistency. With the exception of the 2-ounce grenade, there was a trend for decreasing accuracy with increasing weight.

1. Psychology   2. Motor Skills   3. Control Coordination

DISTRIBUTION LIST FOR AMRL REPORTS

Category (A)

ARMY	Copies
The Surgeon General Department of the Army Main Navy Building Washington 25, D. C. ATTN: Chief, Research and Development Division	10
Director Armed Forces Institute of Pathology Walter Reed Army Medical Center Washington 12, D. C.	1
Army Library Room 1A 522, The Pentagon Washington 25, D. C. ATTN: National Defense Review	1
Headquarters Army Medical Service Graduate School Walter Reed Army Medical Center Washington 12, D. C.	1
Chief, Human Relations & Research Branch Military Personnel Management Division Office of Assistant Chief of Staff Department of the Army Room 2C724, The Pentagon Washington 25, D. C.	2
Office Assistant Chief of Staff, G4 Department of the Army The Pentagon Washington 25, D. C. ATTN: Research & Development	1
Commanding Officer Chemical Corps Medical Laboratories Army Chemical Center, Maryland ATTN: Chief, Technical Information Branch	1
Army Environmental Health Laboratory Building No. 1235 Army Chemical Center, Maryland	1
Commandant Marine Corps Schools Quantico, Virginia ATTN: Library and Record Section, MCEC	1
Medical Field Service School Fort Sam Houston, Texas	2
Supreme Headquarters of the Allied Powers in Europe Medical Section Rocquencourt, France	2
Office, Chief of Army Field Forces Fort Monroe, Virginia	1
Walter H. Moursund, Jr., Colonel GS Office of the Army Attache, Box 36 U. S. Navy 100 Fleet Post Office New York, New York	2
Commanding General Headquarters, QM R&D Command QM R&D Center, U. S. Army Natick, Massachusetts	3
Commanding Officer Medical Nutrition Laboratory 9937 TU U. S. Army Fitzsimmons Army Hospital Denver 7, Colorado	1
Headquarters 406th Medical General Laboratory APO 500, c/o Postmaster San Francisco, California	1
Headquarters Camp Detrick Frederick, Maryland ATTN: Technical Library	1
Scientific Publications and Reports Office QM Food and Container Institute for the Armed Forces 1819 West Pershing Road Chicago 9, Illinois	1
Commanding Officer Arctic Test Branch, OCAFF (AAU 8576) APO 733, c/o Postmaster Seattle, Washington	1
Librarian Veterans Administration Hospital Little Rock, Arkansas	1

NAVY	
U. S. Naval School of Aviation Medicine U. S. Naval Air Station Pensacola, Florida	1
Commanding Officer Naval Medical Research Institute National Naval Medical Center Bethesda 14, Maryland	1
Commanding Officer U. S. Naval Air Development Center Johnsville, Pennsylvania ATTN: Aviation Medical Acceleration Lab.	1
Officer in Charge U. S. Naval Medical Research Laboratory U. S. Naval Submarine Base New London, Connecticut ATTN: Librarian	1

Category (A) Continued

NAVY

	Copies
Chief, Bureau of Medicine & Surgery Department of the Navy Washington 25, D. C.	1
Commanding Officer Naval Medical Field Research Lab. Marine Barracks Camp Lejeune, N. C.	1
Special Assistant for Bio Sciences Office of Naval Research Department of the Navy Washington 25, D. C.	1
Superintendent U. S. Naval Postgraduate School Monterey, California ATTN: Librarian	1

AIR FORCE

	Copies
Commandant USAF School of Aviation Medicine Randolph Air Force Base Randolph Field, Texas ATTN: Research Secretariat	1
Commander HQ Wright Air Development Center Wright-Patterson Air Force Base, Ohio ATTN: Aero Medical Laboratory (WCRD) Directorate of Research	1
Director Air University Library Maxwell Air Force Base, Alabama	1
Department of the Air Force Headquarters USAF Director, Research & Development DCS/D Washington 25, D. C. ATTN: AFDRD-HF	1
Arctic Aeromedical Laboratory APO 731, c/o Postmaster Seattle, Washington ATTN:Librarian, AAL	1
Commander Air Research and Development Command ATTN: RDTRH P. O. 1935 Baltimore 3, Maryland	1

OTHER AGENCIES

	Copies
Exchange and Gift Division Library of Congress Washington 25, D. C.	1
Director, Armed Forces Medical Library 7th Street & Independence Ave, SW Washington 25, D. C. ATTN: Acquisitions Division	1
Operations Research Office The Johns Hopkins University 7100 Connecticut Ave Chevy Chase, Maryland ATTN: Librarian	1
National Institutes of Health Division of Research Grants Bethesda 14, Maryland	2
Armed Services Technical Information Agency Document Service Center Knott Building Dayton 2, Ohio ATTN: DSC-SD32	5
National Science Foundation 2101 Constitution Ave Washington, D. C.	1
Department of Physiology University of Rochester School of Medicine and Dentistry 260 Crittenden Blvd Rochester, New York	1
National Research Council Division of Medical Science 2101 Constitution Ave Washington, D. C.	1

FOREIGN ADDRESSEES

	Copies
Defense Research Member Canadian Joint Staff (W) 2001 Connecticut Ave., NW Washington 8, D. C.	2
Tropical Research Medical Laboratory School of Tropical Medicine University of Puerto Rico San Juan, Puerto Rico	1
RCAMC Liaison Officer Surgeon General's Office Department of the Army Room 2842 Main Navy Building Washington 25, D. C.	2
Dr. O. G. Edholm Head, Division of Human Physiology Medical Research Council Laboratory Holly Hill, Hampstead London, NW 3 England	1

Category (A) Continued

FOREIGN ADDRESSEES	Copies
THRU: The Foreign Service of the United States of America United States Army Liaison Office American Consulate General Singapore (for clearance and forwarding to:) The Deputy Director of Army Health Far East Land Forces Singapore	1
British Naval & Army Medical Liaison Officer Bureau of Medicine & Surgery Building 4, Room 60A 23rd and E Streets Washington, D. C.	2

DISTRIBUTION LIST FOR AMRL REPORTS

Category (D)

ARMY	Copies
Commanding General Aberdeen Proving Ground, Maryland ATTN: Human Engineering Laboratory	1
Commanding Officer Army Field Forces Human Research Unit #1 The Armored Center Fort Knox, Kentucky	1
Quartermaster Board Fort Lee, Virginia	1
President Board #2, OCAFF Fort Knox, Kentucky	1
President Board #3, OCAFF Fort Benning, Georgia	1
Commanding Officer Frankford Arsenal Philadelphia 37, Pennsylvania ATTN: Human Engineering Mission (LC)	1
Ordnance Corps Detroit Arsenal Center Line, Michigan ATTN: Mr. J. D. Gallombardo XRDMX-ECG	1
Commandant, Adjutant General's School Office of the School Secretary Fort Benjamin Harrison Indianapolis 16, Indiana	1
Adjutant General's Office Personnel Research Branch Department of the Army Washington 25, D. C.	1
President, Army Field Forces Board #1 Fort Bragg, North Carolina	1
President, Army Field Forces Board #4 Fort Bliss, Texas	1
Chief, Army Field Forces Human Research Unit #2 P.O. Box 446 Fort Ord, California	1
Director Human Resources Research Office P.O. Box 3596 Washington 7, D. C. ATTN: Library	1
Human Research Unit #3 Office, Chief of Army Field Forces Fort Benning, Georgia	1
Operations Research Office 6410 Connecticut Avenue Chevy Chase, Maryland ATTN: The Library	1
Office, Chief of Ordnance ATTN: ORDTB-PS, The Pentagon Washington 25, D. C.	1
Operations Personnel Research Div Office of Chief, Research & Development Deputy Chief of Staffs for Plans & Research Room 2C 734, The Pentagon Washington 25, D. C.	1
Office of Chief Signal Officer Room 2E 258, The Pentagon Washington 25, D. C.	1
Commanding Officer Transportation Research & Development Station Fort Eustis, Virginia	1

NAVY	Copies
Director Naval Research Laboratory Washington 25, D. C.	1
Commanding Officer U. S. Naval Medical Research Unit #1 Bldg T-19, University of California Berkeley 4, California	1
Officer-in-Charge U. S. Naval Personnel Research Field Activity Tempo "T" 14th & Constitution Ave., NW Washington 25, D. C.	1
Director, U. S. Naval Air Experimental Station ATTN: Supt., Aero Medical Equipment Laboratory Philadelphia 12, Pennsylvania	1
Commander U. S. Naval Air Test Center Patuxent River, Maryland ATTN: Physiological Test Section of Service Test	1
U. S. Navy Electronics Laboratory ATTN: Head, Human Factors Division San Diego 52, California	2

Category (D) Continued

NAVY	Copies
Director, Operations Evaluation Group (OP-374) Room 4D 541, The Pentagon Washington 25, D. C.	1
Psychological Research & Applications Department Special Devices Center Port Washington, L. I., New York	1
Office of Naval Research Psychophysiological Psychology Branch, Code 454 Department of the Navy Washington 25, D. C.	1

AIR FORCE	Copies
Commander Air Force Operational Test Center ATTN: Technical Reports Branch Eglin Air Force Base, Florida	1
Commander Lackland Air Force Base San Antonio, Texas	1
Assistant for Ground Safety DCS/Pers, Headquarters, USAF Washington 25, D. C.	1
AFPT Research Center Liaison Officer Deputy Chief of Staff Operations, Headquarters Air Training Command Scott Air Force Base, Illinois	1
Director Armament Systems Personnel Research Laboratory Lowry Air Force Base, Colorado	1
Director Basic Pilot Goodfellow Air Force Base, Texas	1
Human Factors Operations Research Laboratory Air Research and Development Command, USAF Bolling Air Force Base Washington 25, D. C.	4
The Rand Corporation 1700 Main Street Santa Monica, California ATTN: Mr. Victor M. Hunt	1

INDIVIDUALS	Copies
Dr. Frank A. Geldard Peabody Hall University of Virginia Charlottesville, Virginia	1
Dr. William E. Kappauf, Jr. Department of Psychology University of Illinois Urbana, Illinois	1
Dr. Lorrin A. Riggs Department of Psychology Brown University Providence 12, Rhode Island	1
Dr. Eliot Stellar Johns Hopkins University Psychology Department Baltimore 18, Maryland	1
Dr. Merle Lawrence S. S. Kresge Medical Research Bldg University of Michigan Ann Arbor, Michigan	1
Dr. William A. Hunt Department of Psychology Northwestern University Evanston, Illinois	1
Dr. Anthony Lanza Institute of Industrial Medicine New York University Bellevue Medical Center 477 First Avenue New York, New York	1
Dr. Harold Schlosberg Psychology Laboratory Brown University Providence 12, Rhode Island	1
Dr. Willard Machle Boca Raton, Florida	1
Dr. Norton Nelson Institute of Industrial Medicine New York University Bellevue Medical Center 477 First Avenue New York, New York	1

OTHER AGENCIES	Copies
Director, Bibliographical Services Project Institute for Applied Experimental Psychology North Hall, Tufts College Boston 14, Massachusetts	1
Department of Psychology University of Rochester Rochester 3, New York	1

REPORT NO. 176

PERFORMANCE WITH LIGHT-WEIGHT GRENADES AS A FUNCTION OF WEIGHT AND DISTANCE*

by

Bryce O. Hartman, Capt, MSC, and
Robert E. Page, SFC

from

PSYCHOLOGY DEPARTMENT
ARMY MEDICAL RESEARCH LABORATORY
Fort Knox, Kentucky
8 February 1955

*Subtask under PSYCHOPHYSIOLOGICAL STUDIES, AMRL Project No. 6-95-20-001, Subtask, Control Coordination Studies.

Report No. 176
Project No. 6-95-20-001
Subtask AMRL S-1
MEDEA

ABSTRACT

PERFORMANCE WITH LIGHT-WEIGHT GRENADES AS A FUNCTION OF WEIGHT AND DISTANCE

OBJECT

In this study, the effect of weight and distance on the accuracy and consistency of throwing was investigated. Five weights were selected from a range which was considerably below the standard. Six distances were used.

RESULTS AND CONCLUSIONS

Each increase in distance resulted in a decrement in the accuracy and consistency with which the subjects threw. With the exception of the 2-ounce grenade, there was a trend for a decrease in the accuracy and consistency of throwing with increasing weight. Accuracy with the 2-ounce grenade was significantly different from that with all other weights. The graphic analyses and observations during the experiment suggested that throwing the 2-ounce grenade was a qualitatively different task than throwing the other weights. It was not possible to relate performance to effort in any systematic fashion.

RECOMMENDATIONS

Light-weight grenades should not be designed to weigh less than 6 ounces until the effect of changes in the characteristic trajectory and throwing technique with light objects is evaluated.

The relationship between accuracy and effort should be more precisely determined. A reactive force platform appears to be a promising instrument for this determination.

Submitted 30 December 1954 by:
Bryce O. Hartman, Capt, MSC
Robert E. Page, SFC

APPROVED: Ray G. Daggs
RAY G. DAGGS
Director of Research

APPROVED: [illegible] Lt. Col. MSC
for WILLIAM W. COX
Lt Colonel, MC
Commanding

PERFORMANCE WITH LIGHT-WEIGHT GRENADES AS A FUNCTION OF WEIGHT AND DISTANCE

I. INTRODUCTION

The hand grenade is one of the weapons used by a soldier in close combat. Its effectiveness is determined by many factors, including the skill and training of the thrower, the conditions under which it is thrown, the environment, and the design of the grenade itself. This laboratory has been conducting a series of studies in which the design of the grenade and the conditions under which it is thrown have been investigated. The basic approach has been that grenade throwing is a gross psychomotor task, involving a large amount of force and a lesser amount of fine control (coordination) and skill.

In two previous reports, the variables under study were the shape and weight of the grenade and the distance it was thrown. None of the five shapes which were studied significantly improved performance (1, 2). Both weight and distance significantly altered performance. In AMRL Report No. 153 (2), weight and distance were combined into an effort measure and a curve was drawn showing the relationship between effort and accuracy.

This study is an extension of the attempt to combine weight and distance into an effort measure as well as an evaluation of performance with light-weight grenades. Five weights and six throwing distances were used. The distances were 10, 15, 20, 25, 30, and 35 yards. The weights were 2, 4, 6, 8, and 10 ounces. While these weights are considerably below the weight of the standard fragmentation grenade, the results can be generalized to a variety of motor tasks in which the gross effort of throwing is a component.

Because of the intention to combine weight and distance into an effort measure, a factorial design was used in this study; both variables were studied simultaneously. Both accuracy (radial distance from the target center) and consistency (dispersion, or the scatter of the throw) were used as measures of performance.

II. EXPERIMENTAL PROCEDURE

A. Apparatus

The grenades consisted of facsimiles of the standard fragmentation grenade, except that there was no arming mechanism and the body was not serrated. They were made of wood, drilled out or weighted with lead, as necessary to obtain 2, 4, 6, 8, and 10 ounces. Care was taken in adding lead to assure that the grenades were properly balanced. Five grenades of each weight were used. The weights obtained were within one-half ounce of the desired weight.

The target consisted of a horizontal, bull's-eye type of target area, with a two-by-four post one foot tall at the center. A series of reference pins (concentric to the center) were laid out in a circle which had a radius of 11 feet. The pins were set at 5° intervals, running clockwise, with zero being on the line between the center post and the subject. Tags, giving the angular values, were placed upon the pins. A movable barricade, measuring 4 feet high and 4 feet wide, was used to insure that the thrower was at the specified distance from the target and all throws were made overhand. Distance pegs were placed in a line at 5-yard intervals, starting 10 yards from the target and going out to 35 yards. Since this study was run in the desert, care was taken to select an experimental area which had sufficient visual structure to provide effective depth cues and reduce the contribution of the perceptual component to the total error.

B. Subjects

Twelve men from the laboratory were employed as subjects. They were in good health, had no physical deformities of the throwing arm or hand, and had served as subjects in previous grenade studies.

C. Scoring

All throws were recorded in terms of distance to the nearest inch from the bull's-eye, and in terms of direction to the nearest 5°. A hit on the center post was recorded as zero in distance and direction. The score was taken at the initial point of contact, with the roll of the grenade disregarded.

D. Procedure

Subjects made five throws of each weight of grenade at every distance. To minimize fatigue, subjects threw only thirty times in each day. All twelve subjects threw one weight in a single day. All thirty throws by a subject were made in succession. Subjects threw from the six distances in a predetermined random order. Throwing order was systematically balanced between subjects and no two subjects threw in the same order. Each throwing order was used five times (once for each weight) for the subject assigned to it, with the orders reversed in the second and fourth days of the series.

For each session the men were organized into teams of three. These teams included a thrower, a scorer, and a tape man. Subjects rotated at all three positions. In addition to the scoring teams, there were 3 supervisors on the field during the session.

The procedure for each throw was as follows: The movable barricade was set up at the designated distance. The subject crouched behind the barricade with a grenade in his hand. On the command, "Throw," the subject stood up, threw, and returned to the crouched position.

At the target area, the scorer pushed a pencil into the ground at the initial point of contact for the throw. The tape man moved around the outside ring of the target so that the tape stretched tight against the side of the pencil. The throw was recorded in distance from the center of the target to the nearest inch and in direction to the nearest 5^{o} marked on the reference pin closest to the tape as it crossed the outer circle.

III. RESULTS

A total of 1,800 scores were obtained, five for each of the 12 subjects, on every combination of 5 weights and 6 distances. A mean was calculated for each group of 5 throws. These individual means were then summarized into 30 group means, one for each combination of weight and distance. Two kinds of means can be computed from these types of scores. The first, which will be called the radial mean, can be obtained from the sum of the error (distance from the center of the target) disregarding the angular values which were recorded. The second, which will be called the trigonometric mean, is obtained by converting distance and direction scores to rectangular coordinates, summing the two coordinates separately, computing coordinate means, and then combining them trigonometrically into a radial mean by the formula

$$M_R = \sqrt{M_x^2 + M_y^2} \; *$$

The second type of mean was chosen for analysis because it defines

*The procedure and an example are presented in (1).

a specific point in space, gives a better representation of a distribution of throws, and permits better predictions.

In addition to the means, which are a measure of accuracy for each of the grenades, standard deviations were obtained trigonometrically. The procedure used for this computation was similar to that used for computing the mean error scores. Standard deviations for the X axis scores and the Y axis scores were computed separately and then combined in the formula

$$\sigma R = \sqrt{\sigma_x^2 + \sigma_y^2} *$$

The resulting 30 standard deviations, which are measures of consistency, are an important tool for evaluating performance. A grenade with a large scatter but whose mean score is exactly on the target may not be as good a grenade as one with a very small scatter and a mean close to, but not on, the target. With this latter grenade, the thrower has a better chance that any single throw will be close enough to the enemy to cause damage.

Mean radial error scores, mean Y-axis error scores, and standard deviations for each of the weights and distances are presented in Table 1. The mean Y scores will be used in the figures

TABLE 1

MEANS (RADIAL AND 'Y' AXIS) AND STANDARD DEVIATIONS
FOR EACH COMBINATION OF WEIGHT OF GRENADE AND DISTANCE OF TARGET

	Weight (in Ounces)														
	2			4			6			8			10		
Distance (in Yards)	Mr	My	SD	Mr	My	SD	Mr	My	SD	Mr	My	SD	Mr	My	SD
10	1.50	1.50	2.16	1.32	1.27	1.25	1.24	1.12	1.02	0.90	1.03	0.83	1.51	1.51	1.08
15	0.29	-0.29	1.98	0.15	0.15	2.03	0.62	-0.42	1.74	0.11	-0.08	1.48	1.68	1.66	1.28
20	2.75	-1.82	2.72	1.02	1.02	1.58	0.51	-0.10	1.08	0.44	-0.42	1.27	0.30	0.03	0.85
25	2.83	-2.67	2.71	1.07	0.27	2.03	1.18	-0.90	2.15	1.44	-1.43	2.43	2.15	-2.08	2.48
30	4.35	-4.24	2.94	2.01	-2.01	2.54	1.92	-0.54	2.35	2.34	-2.18	2.52	2.78	-2.23	2.25
35	8.63	-8.36	3.85	2.32	-2.23	2.85	1.94	-1.58	2.53	4.02	-3.74	2.71	5.54	-5.90	4.23

Mr = Mean radial error, obtained trigonometrically.

My = Mean error on the Y axis.

SD = Standard deviation, obtained trigonometrically.

*The procedure and an example are presented in (1).

because they permit throws short of the target to be plotted separately from throws beyond the target. These scores were subjected to graphic analyses and also to analysis of variance, with the appropriate F's and t's being computed.

A. Graphic Analyses

Figures 1 through 5 present the 360 individual subject means plotted on a schematic view of the target. Each point is the mean of 5 throws for a single subject. Each figure represents all the points for one weight at every distance. The X on each bull's-eye represents the trigonometric mean for the 12 points which have been plotted. With minor exceptions, the general results suggested in these figures can be summarized in the following way. As distance increases, accuracy changes in a systematic fashion. The figures show that subjects in general overthrow on short distances and progressively underthrow with increasing distance. In general, as distance increases, the scatter of 12 points on each bull's-eye increases. When the five figures are examined as a group, a similar trend for weight can be seen. As weight increases mean error increases, with the same general overthrow-underthrow relations obtained with distance. Changes in the scatter as weight increases are not clear in these figures and will be discussed later. It is interesting to note that all the means for the 10-yard throws are beyond the target.

Figures 6 and 7 summarize changes in accuracy (mean error on the Y axis) and as a function of distance and weight. Each point is the trigonometric mean of all throws for each weight or distance. The pronounced effect of distance is clear in Figure 6. In Figure 7 a marked deviation from a trend of increasing error with greater weight can be seen. Mean error for the 2-ounce grenade is grossly greater than with the other weights. Examination of the plots in Figures 1 through 5 shows that this deviation increases progressively as distance increases, both for individual subjects and for the means of all twelve subjects.

Figures 8 and 9 summarize changes in consistency as a function of distance and weight. The marked and progressive effect of distance on consistency is clear in Figure 8. An optimum for weight at 6 ounces is indicated in Figure 9. This may be an artifact due to the deviation from the general trend when the subjects threw the lightest grenade, which has previously been discussed.

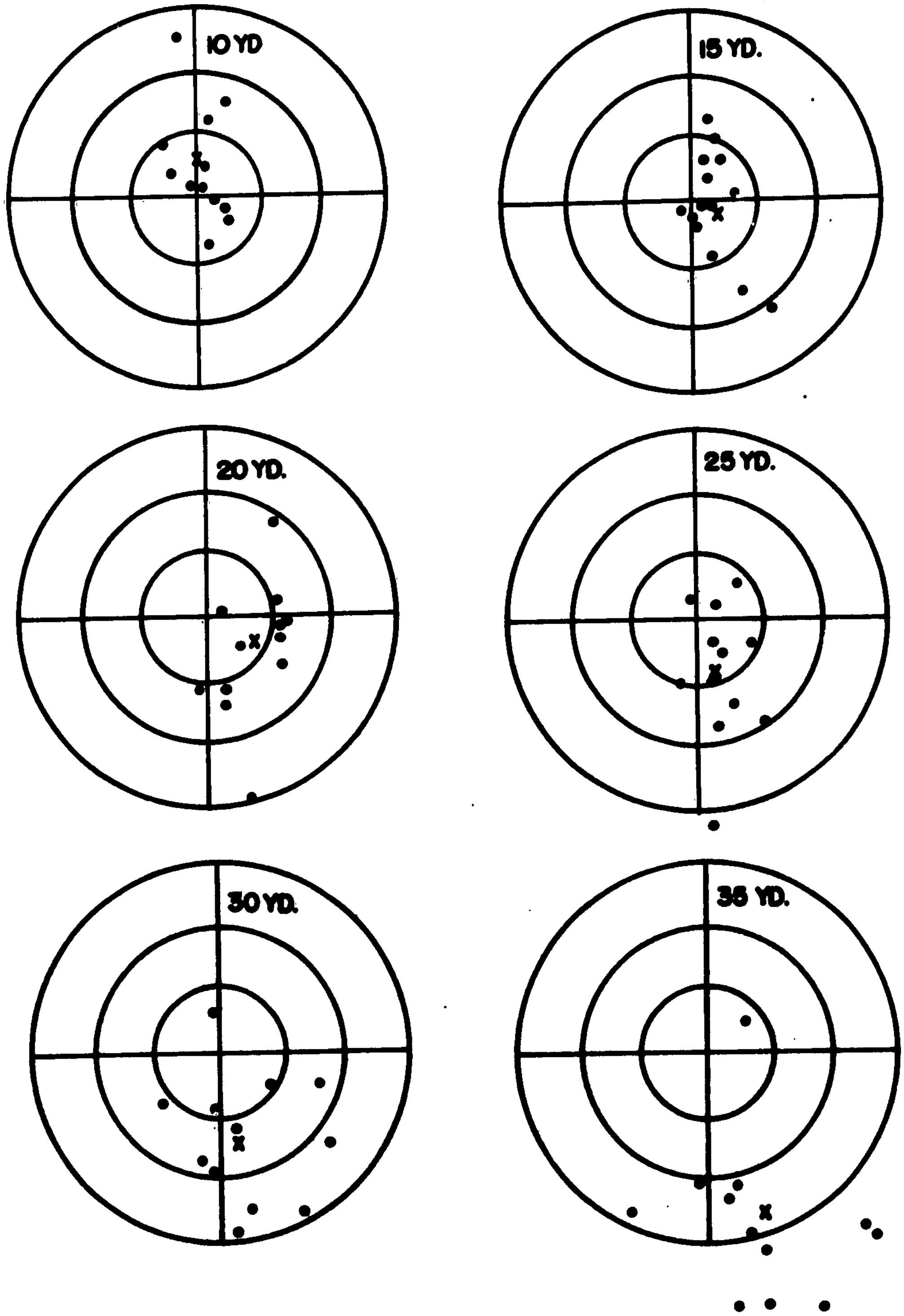

FIG. I. MEANS FOR THE 2-OUNCE GRENADE AT EACH TARGET DISTANCE PLOTTED ON A SCHEMATIC VIEW. RINGS ARE AT ONE-FOOT INTERVALS. GRAND MEAN FOR EACH DISTANCE IS INDICATED BY "X".

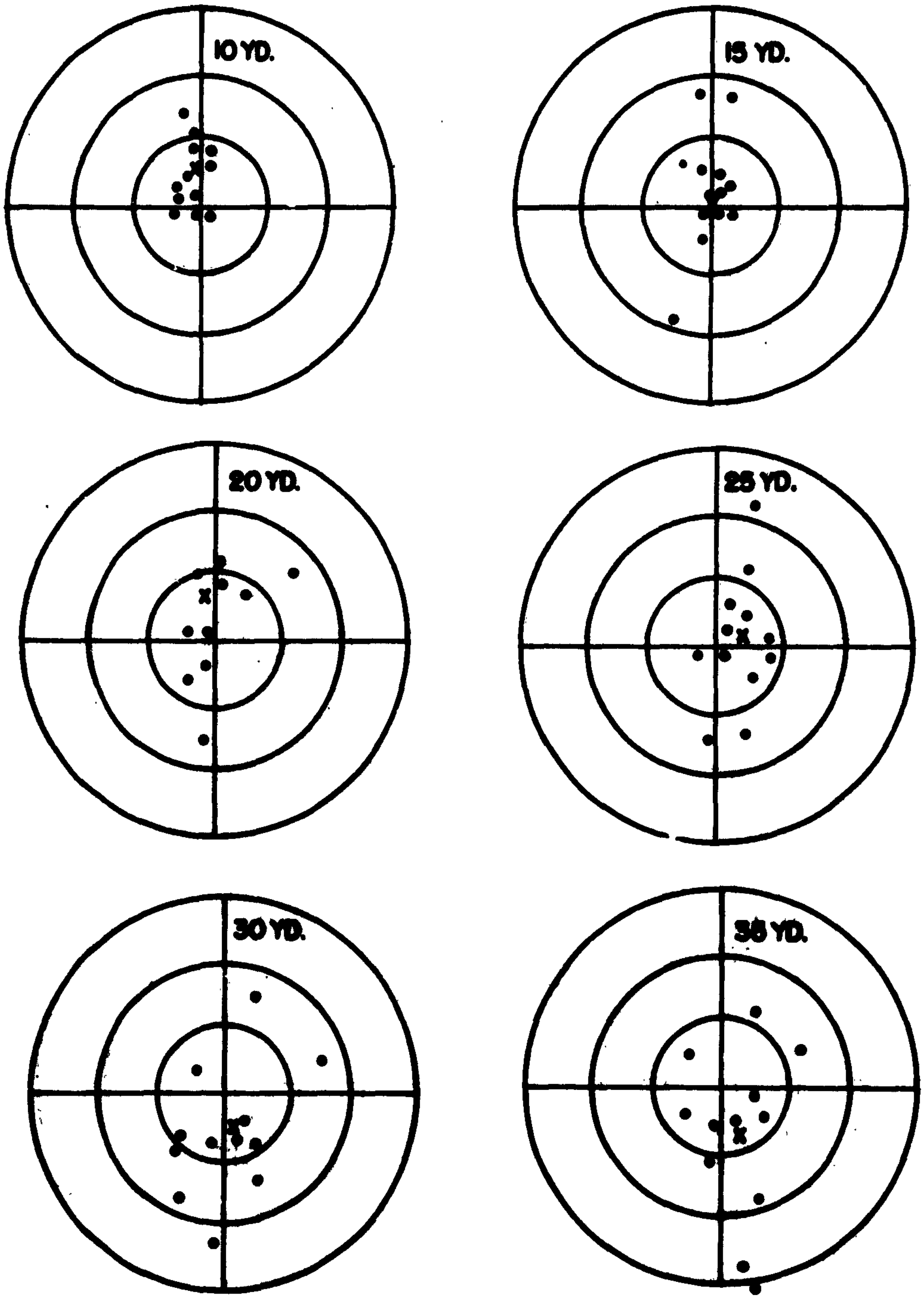

FIG. 2. MEANS FOR THE 4-OUNCE GRENADE AT EACH TARGET DISTANCE PLOTTED ON A SCHEMATIC VIEW. RINGS ARE AT ONE-FOOT INTERVALS. GRAND MEAN FOR EACH DISTANCE IS INDICATED BY "X".

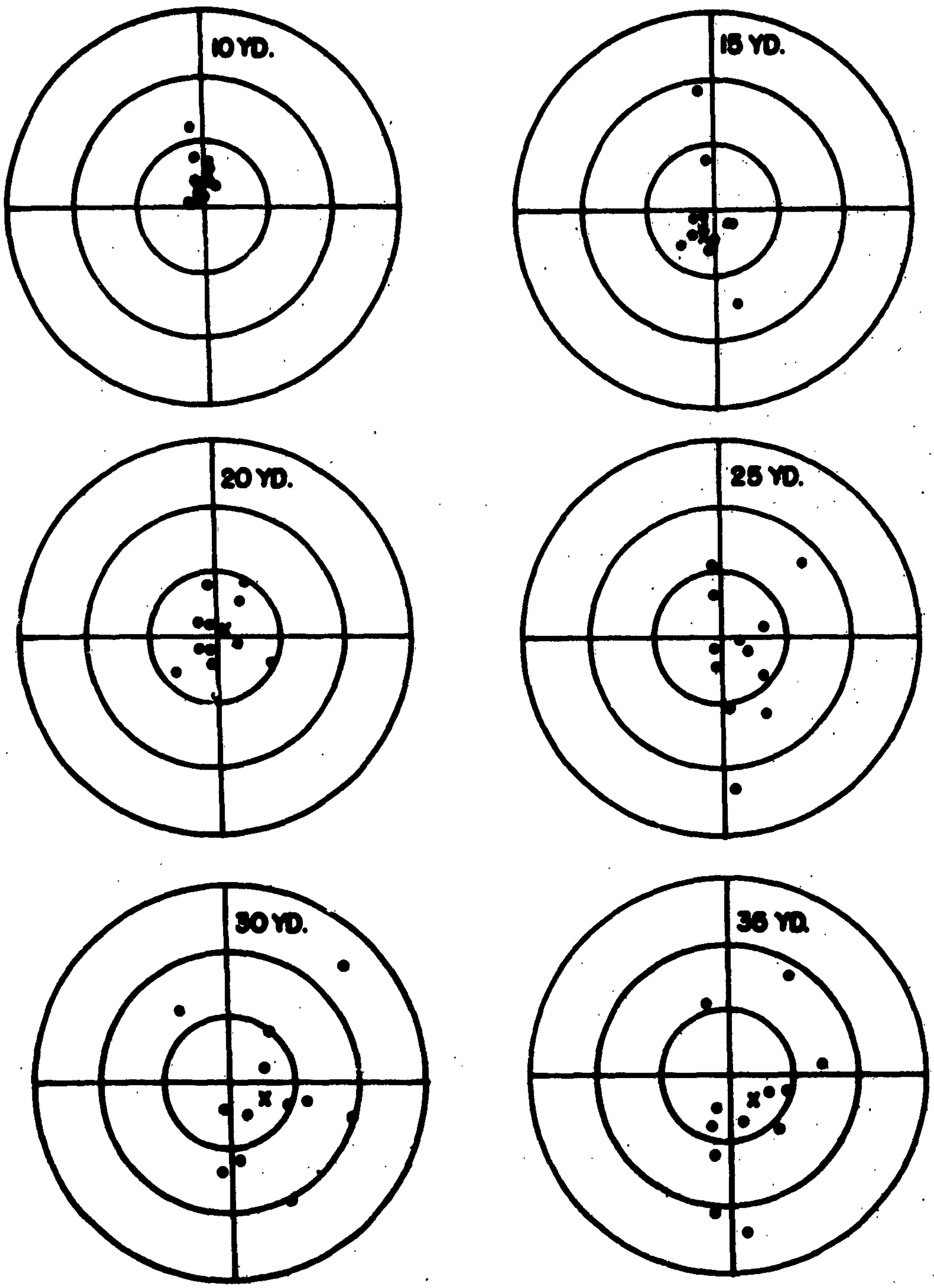

FIG. 3. MEANS FOR THE 6-OUNCE GRENADE AT EACH TARGET DISTANCE PLOTTED ON A SCHEMATIC VIEW. RINGS ARE AT ONE-FOOT INTERVALS. GRAND MEAN FOR EACH DISTANCE IS INDICATED BY "X".

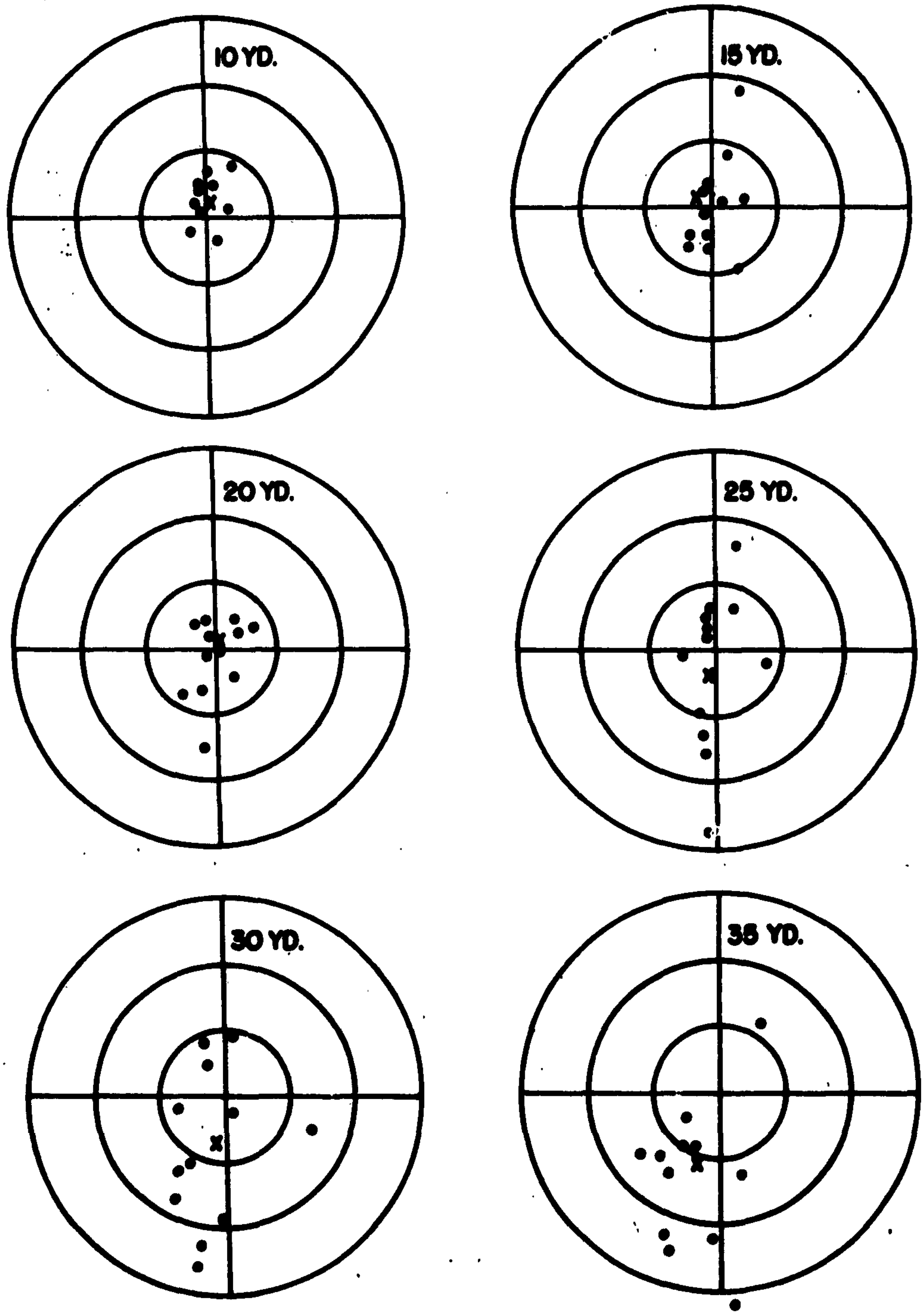

FIG. 4. MEANS FOR THE 8-OUNCE GRENADE AT EACH TARGET DISTANCE PLOTTED ON A SCHEMATIC VIEW. RINGS ARE AT ONE-FOOT INTERVALS. GRAND MEAN FOR EACH DISTANCE IS INDICATED BY "X".

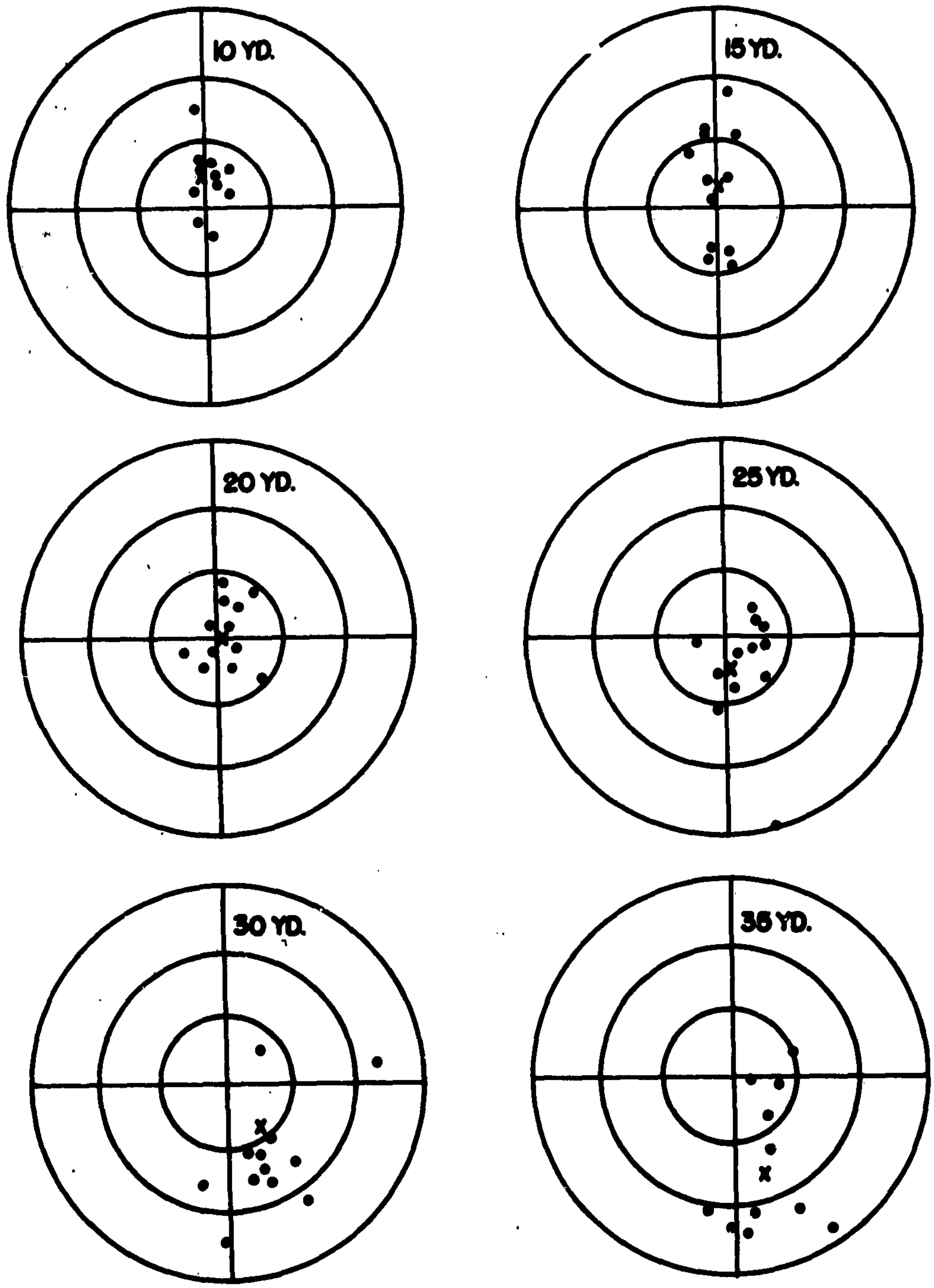

FIG. 5. MEANS FOR THE 10-OUNCE GRENADE AT EACH TARGET DISTANCE PLOTTED ON A SCHEMATIC VIEW. RINGS ARE AT ONE-FOOT INTERVALS. GRAND MEAN FOR EACH DISTANCE IS INDICATED BY "X".

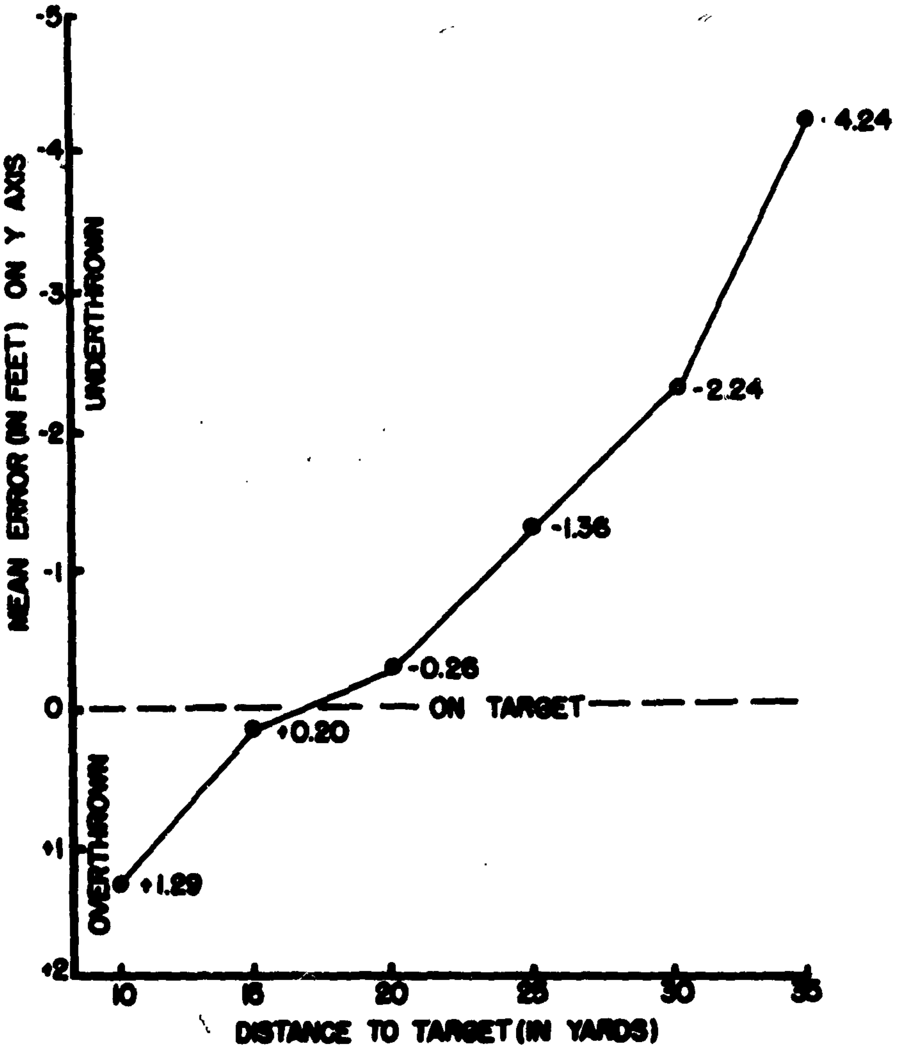

FIG. 6. THE EFFECT OF DISTANCE ON THE ACCURACY OF THROWING HAND GRENADES.

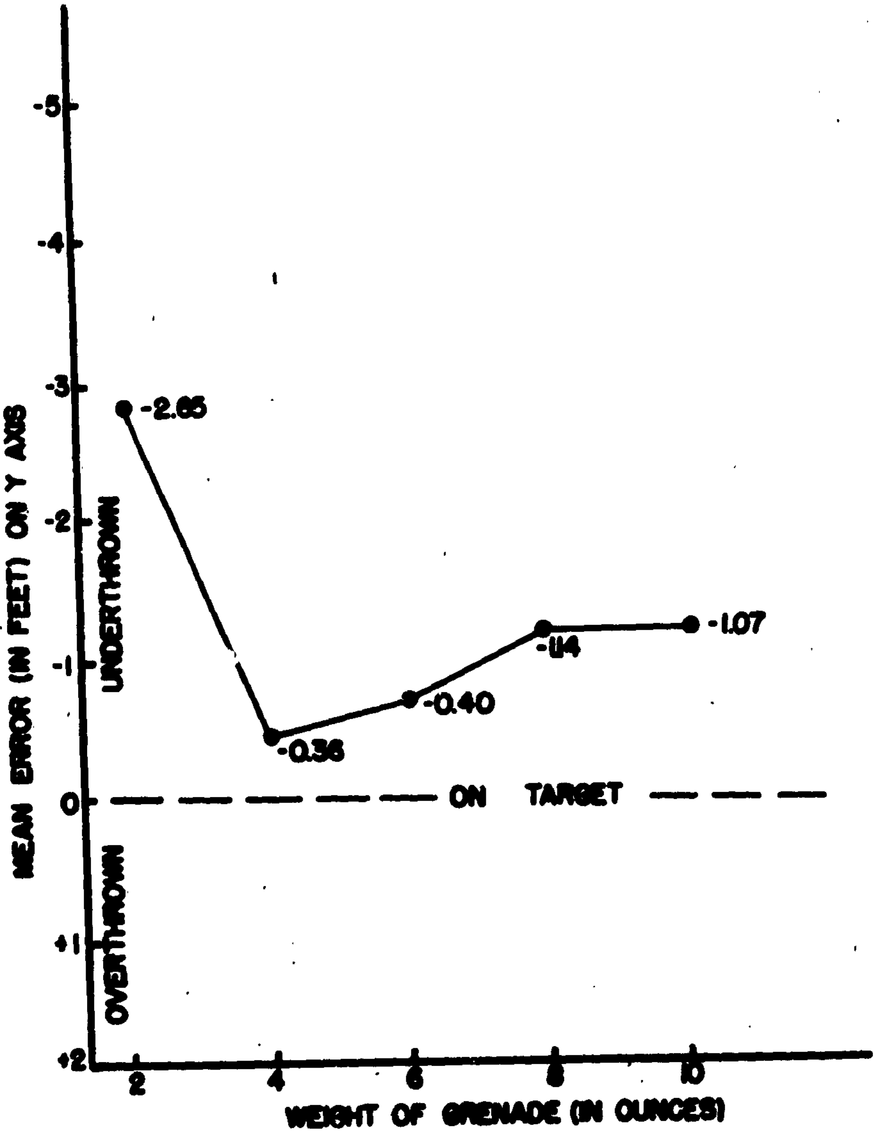

FIG. 7. THE EFFECT OF WEIGHT ON THE ACCURACY OF THROWING HAND GRENADES.

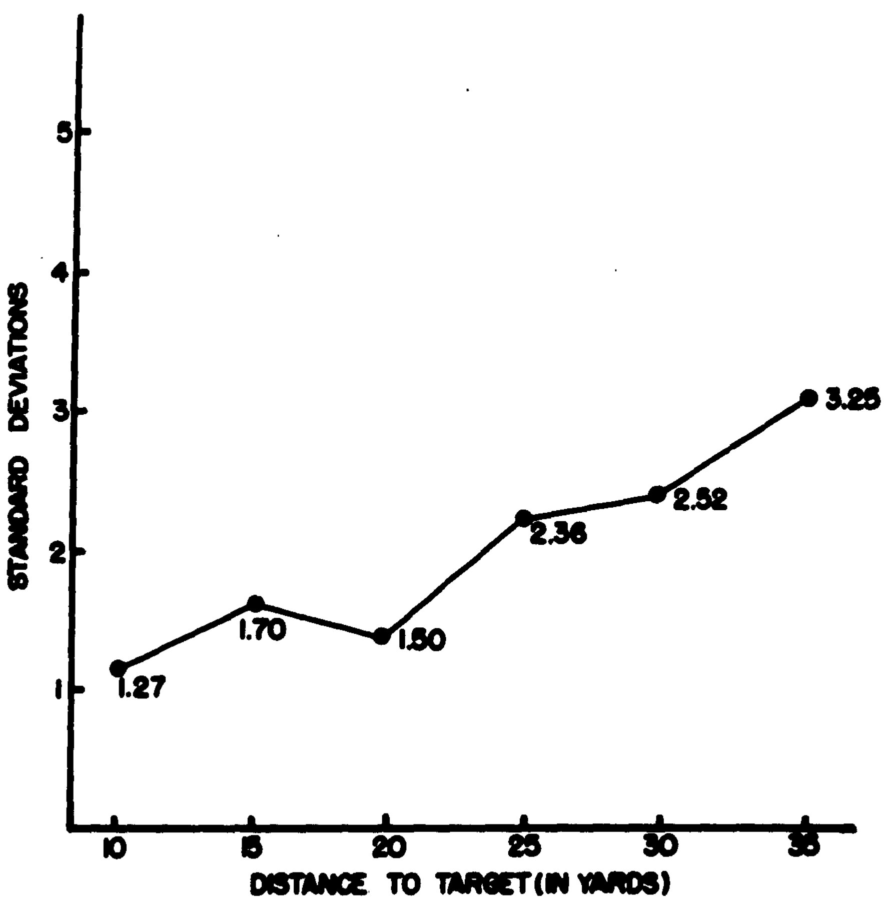

FIG. 8. THE EFFECT OF DISTANCE ON THE CONSISTENCY OF THROWING HAND GRENADES.

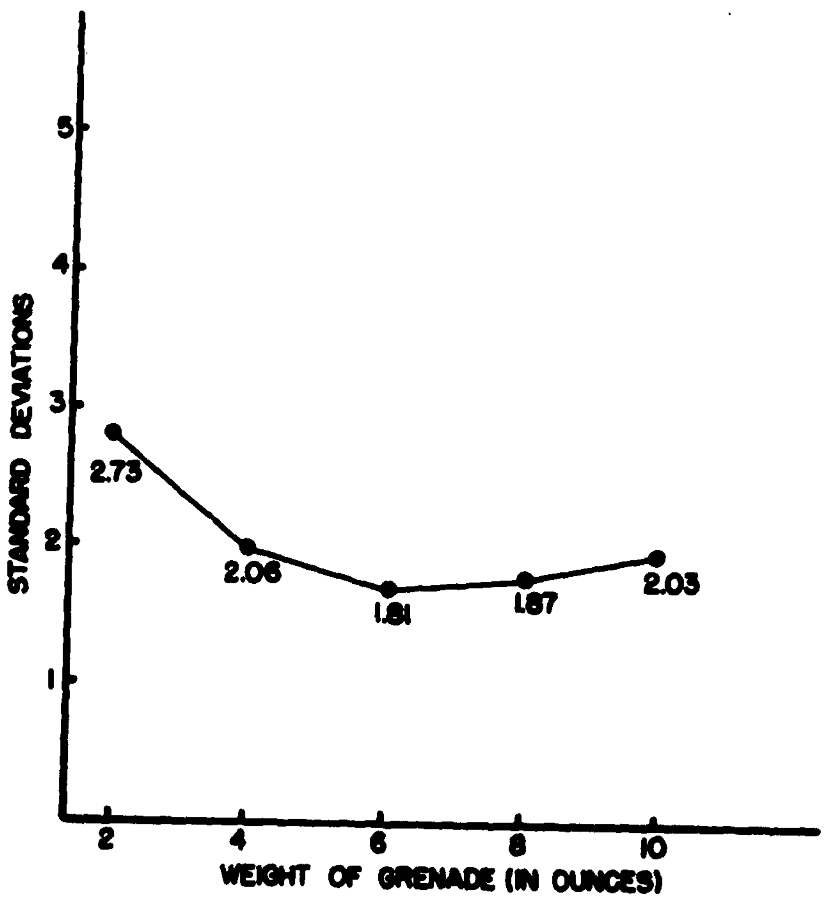

FIG. 9. THE EFFECT OF WEIGHT ON THE CONSISTENCY OF THROWING HAND GRENADES.

B. Statistical Analyses

The effect of weight and distance on accuracy was evaluated by an analysis of variance, using subject means in each cell. The design of this analysis of variance can be described as a double classification analysis, 12 subjects (scores) per cell, the same subjects in every cell. Table 2 presents the results of the analysis of variance of mean error scores. As the table shows, a significant F was obtained for the interaction between weight and distance when it was tested against the residual. The interaction term was therefore used in the test of significance for weight and for distance. In both cases significant F's were obtained. It should be noted that the variance ΣX^2 divided by the df in Table 2) for distance is larger by a factor of approximately 4 than the variance for weight or the interaction of weight and distance.

TABLE 2

ANALYSIS OF VARIANCE OF ACCURACY (MEAN ERROR)

Source of Variation	ΣX^2	df	F
Weight	173.315	4	16.61**
Distance	662.123	5	5.44**
Wt. X Dist.	159.496	20	2.20**
Residual	1155.892	319	
Subjects	100.539	11	
Total	2251.365		

**Significant at 1% level.

Table 3 presents results of "t" tests of the significance of the differences between means for weights and for distance. These "t's" were obtained by the difference technique. For distance, all pairs were significant except for the adjacent pairs in the 15, 20, and 25 yard portion of the range. For weight, accuracy with the 2-ounce grenade is significantly poorer than that with any other grenade. The 6-ounce grenade differed significantly from the 10-ounce grenade. All other combinations were not significant.

TABLE 3

TESTS OF SIGNIFICANCE OF DIFFERENCES BETWEEN MEAN ERROR FOR WEIGHT AND DISTANCE
('t' obtained by the difference technique)

Weight		Distance	
Mean Error (ft)	't'	Mean Error (ft)	't'
	t_{2-4} = 4.30**		t_{10-15} = 2.12*
2 oz = 4.56	t_{2-6} = 3.42**	10 yds = 1.75	t_{10-20} = 2.91**
4 oz = 2.88	t_{2-8} = 5.54**	15 yds = 2.29	t_{10-25} = 3.84**
6 oz = 2.60	t_{2-10} = 3.57**	20 yds = 2.43	t_{10-35} = 8.91**
8 oz = 2.89	t_{4-6} = 0.98	25 yds = 3.03	t_{10-35} = 8.57**
10 oz = 3.36	t_{4-8} = 0.00	30 yds = 4.36	t_{15-20} = 0.48
	t_{4-10} = 1.50	35 yds = 5.68	t_{15-25} = 2.19*
	t_{6-8} = 1.11		t_{15-30} = 6.82**
(df = 71)	t_{6-10} = 2.64**	(df = 59)	t_{15-35} = 6.64**
(5% = 1.99)	t_{8-10} = 1.66	(5% = 2.00)	t_{20-25} = 1.97
(1% = 2.65)		(1% = 2.66)	t_{20-30} = 6.77**
			t_{20-35} = 7.52**
			t_{25-30} = 4.01**
			t_{25-35} = 5.55**
			t_{30-35} = 2.97**

* Significant at 5% level.
** Significant at 1% level.

The effect of weight and distance on consistency was evaluated by an analysis of variance, using only one score (the standard deviation of 12 subject means) in each cell. This analysis of variance can be described as a double classification analysis, one score per cell. This design was selected to be used on consistency scores because there were insufficient throws (5 per subject) in each of the 30 conditions to permit individual standard deviations to be computed. For the same reason, t's on consistency for pairs of weights and distances could not be computed. While this design is sufficient for examining the influence of primary variables upon performance, it does not permit a test of the interaction between the two primary variables. The results of the analysis of variance are shown in Table 4. Both weight and distance gave "F's" which were significant beyond the 1% level of confidence. The variance (ΣX^2 divided by the df in Table 4) associated with distance is more than half of the total variance.

TABLE 4

ANALYSIS OF VARIANCE OF CONSISTENCY (STANDARD DEVIATION)

Source of Variation	ΣX^2	df	F
Weight	3.199	4	4.97**
Distance	13.907	5	17.27**
Remainder	3.227	20	
Total	20.333		

** Significant at 1% level.

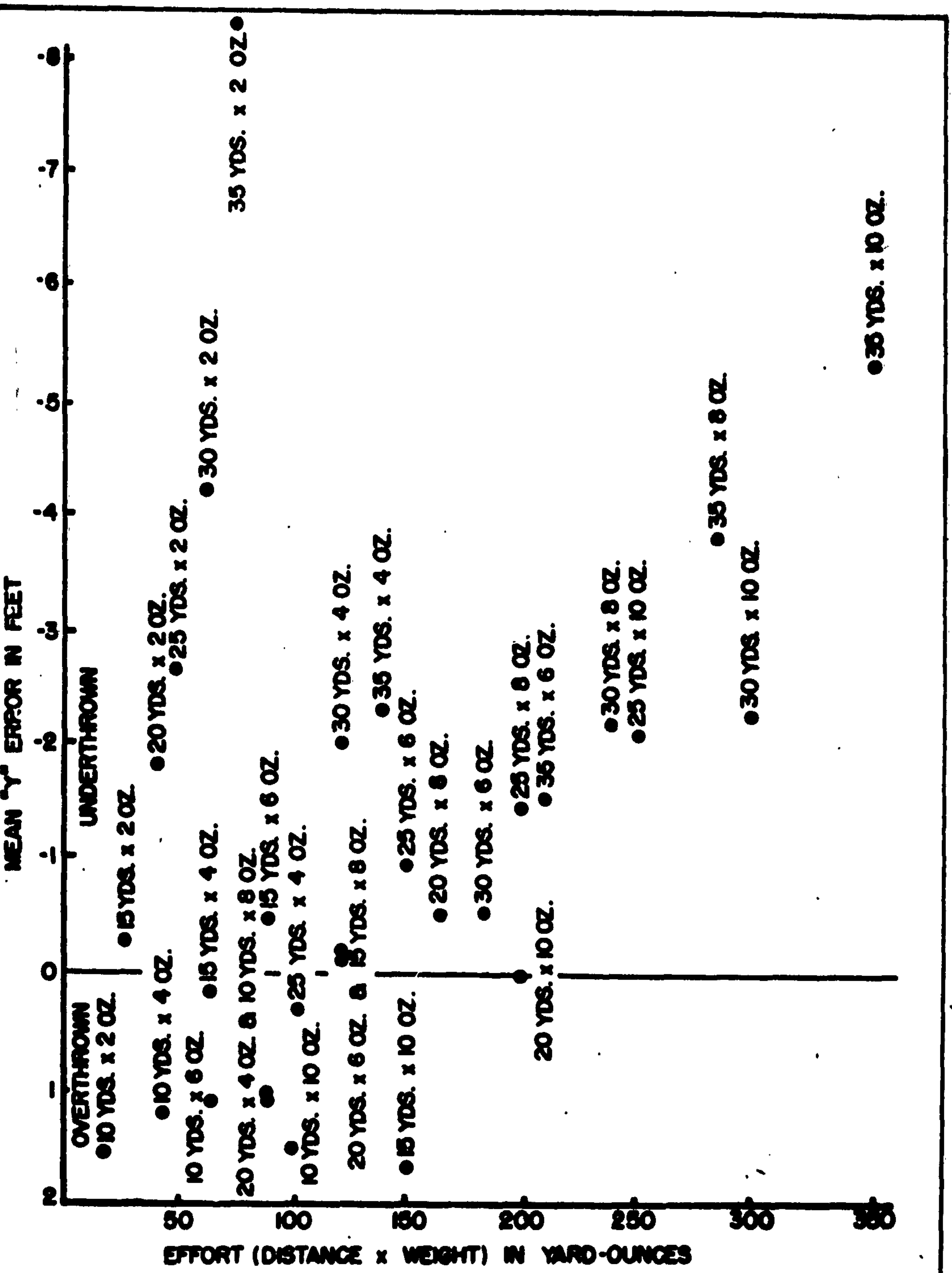

FIG. 10. A PLOT OF ERRORS IN RELATION TO EFFORT FOR ALL OF WEIGHT AND DISTANCE.

In Figure 10, an attempt has been made to relate the accuracy of throwing to effort, by plotting error against a combination of weight and distance. The effort scale (which is, at best, a rough approximation of how hard the grenade was thrown) has units designated yard-ounces, obtained by multiplying the distance to the target by the weight of the grenade. In the previous study (2), this procedure was used and a systematic trend was evident. A curve was fitted by visual approximation. The distribution of the points in Figure 10 is such that no attempt has been made to approximate. a curve plot.

Since an extension of the effort curve from the previous study is one objective of this study, it was necessary to have some method of evaluating the comparability of scores in the two studies. For the instructional period in this study, every subject made 10 throws at each of two distances (20 and 35 yards) with the 18-ounce grenade. Target order was reversed for half of the subjects. All 20 throws were made in succession. Eight of the 12 subjects used in this study had served in the previous study. Their scores for these combinations of weight and distance in the two studies were compared. Differences were tested for significance by computing t's. A "t" of 1.63 was obtained for throws on the 20-yard target. A "t" of 1.01 was obtained for throws on the 35-yard target. Neither was significant at the 5% level of confidence.

IV. DISCUSSION AND CONCLUSIONS

Throughout the graphic and statistical analyses the marked effect of distance on both the accuracy and consistency of throwing grenades is evident. As distance increased both accuracy and consistency decreased.

The results with weight were not so clear-cut. In the analyses of variance, weight yielded significant "F's" for both accuracy and consistency. Examination of the "t's" for accuracy in Table 3 shows that this significance is primarily the result of the difference between the 2-ounce grenade and all other grenades. Figure 7 confirms this general conclusion. Figure 9, which shows the effect of weight on consistency, suggests the same general though less positive conclusion. Examination of the mean Y scores for the 2-ounce grenade, given in Table 1, shows a marked increase in error at the 30-and 35-yard distances. This is probably the reason for the significant difference of the 2-ounce grenade. It appears, from an inspection of the individual means with the 2-ounce grenade on the 30-and 35-yard targets in Figure 1, that these two distances are too far for a man to throw a very light-weight object effectively. A similar but less marked effect can be noted in Table 1 for the 4-ounce grenades at 30- and 35-yards. Observation during the experiment revealed an interesting difference in the way the light grenades were handled.

At the shorter distances, although the throw was overhand, the men made throws which had almost no trajectory at all. Instead, they made a hard, flat throw, directly at the target post. In general, it must be concluded that throwing this extremely light object was a qualitatively different task than, that required by the remainder of the grenades.

The attempt to relate performance of throwing grenades with a crude approximation of effort was fruitless. It was pointed out above that the throwing task with the lighter grenades at the shorter distances was qualitatively different from that of other combinations. This same general effect can be noted in the effort plot, which suggests that some combinations of light weights and short distances, although plotted at the low end of the effort scale, might more appropriately be at the high end of the scale. It is possible that changes in the way a man throws a light object a short distance while striving for maximum accuracy markedly alters the relationship between accuracy and effort found in moderate and high parts of the range.

More adequate measurements of this effort could be obtained by a different technique. When the human throws, he exerts a reactive force with his body which can be directly related to the force imparted to the object thrown. If he threw while standing on a platform instrumented to measure the reactive force, a direct measure of effort might be obtained. This technique is now under consideration.

Three general conclusions come out of this study. First, as distance increases, accuracy and consistency decrease in a systematic fashion. Second, weight significantly alters accuracy and consistency. Third, changes in performance as a function of weight may be related to qualitative differences between throwing light and heavy objects.

The data suggest that these differences occur around 6 ounces, both in terms of accuracy and consistency.

V. RECOMMENDATIONS

Light-weight grenades should not weigh less than 6 ounces.

The relationship between effort and performance at the gross psychomotor task of throwing should be investigated with more precision. Varying amounts of effort could be obtained by having subjects throw objects of several weights at targets located at several distances. A reactive-force platform might provide a more direct and precise measure of the effort expended.

VI. BIBLIOGRAPHY

1. Hartman, B. O., J. T. Burke, and R. Y. Walker. The accuracy of throwing hand grenades as a function of their weight, shape, and size. Army Medical Research Laboratory, Report No. 117, 18 June 1953, Fort Knox, Kentucky.

2. Hartman, B. O. The accuracy of throwing hand grenades as a function of their weight, shape, and distance. Army Medical Research Laboratory, Report No. 153, 2 November 1954, Fort Knox, Kentucky.